SHEAR STRENGTH OF REINFORCED CONCRETE BEAMS WITHOUT STIRRUPS

by

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Dissertation submitted in partial fulfilment of
the requirements for the
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CERTIFICATION OF APPROVAL

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Approved by,

____
(Dr Teo Wee)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
September 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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KERRY TAN TECK SIEW

ABSTRACT

The shear strength of reinforced concrete beams is related to the shear capacity of concrete, concrete compressive strength, tension reinforcement ratio, shear span to depth (a/d) ratio and size effect or depth factor. This study presents experimental work to investigate the shear strength of longitudinally reinforced concrete beams without stirrups of varying shear span to depth ratio under 2-point loading. A total of 3 RC beams are casted with 2T12 bottom steel reinforcement without any internal stirrups. A constant shear force is loaded throughout the shear span. Parameters such as concrete grade, ratio of tension reinforcement, size effect factor and aggregate interlock aspects are kept constant. The 3 beams with a/d ratio of 2.5, 3.0 and 4.0 failed at a load of 23.44 kN, 20.265 kN and 18.145 kN respectively.

ACKNOWLEDGEMENT

First of all, I would like to express my deepest appreciation to my Final Year Project Supervisor, Dr Teo Wee for his guidance throughout the whole 8 months duration of this final year project; for his kind attention, input and words of motivation that has helped me in completing this research.

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INTRODUCTION

1.1 BACKGROUND

For the past few decades, academicians and engineers around the world have been conducting analysis and experimental study on the shear strength of reinforced concrete beams, either with or without transverse reinforcement. Zararis and Papadakis[3] mentioned that plenty of theoretical and research studies have concentrated on beams without transverse reinforcement as it is widely accepted that the understanding of their shear failure mechanism will provide valuable knowledge for the clarification of failure mechanism in beams with transverse reinforcement. However, a fundamental theory to explain the shear failure of beams without transverse reinforcements is yet to be found. Current shear design procedures are commonly considered unacceptable and efforts are being done to revise them. Even though some efforts have met success at the national level, none of the national revisions have been accepted as a widely accepted revision. Thus, attempts are being done to identify the common elements of the various national methods in order to bring together their differences and produce an established shear design procedure.

Beams must have an adequate margin of safety against several types of failures, some of which may be more fatal than flexural failure. Shear failure of reinforced concrete, or commonly known as diagonal tension failure, is complicated and harder to be predicted. In the case of a beam without shear reinforcement being overloaded to failure, shear failure is expected to occur suddenly without prior warning of danger. Even for some reinforced concrete beams that are under-designed, it is noticeable that the cracking and deflections give sufficient warning before the beams completely collapse. This is due to the shear reinforcement which ensured flexural failure will occur before shear failure in the event of severe overloading.

1.2 PROBLEM STATEMENT

Beams fail in two modes, namely flexure and shear. Plain concrete beams are incompetent as flexural members due to its low tensile strength in bending. As a result, the beams fail at low loads on the tension side. Steel reinforcements are usually added on the tension side so that the tension caused by bending moments is resisted by the steel reinforcements.

Shear failure of RC beams is sudden and brittle, which happens without warning before failure, making it more dangerous than flexural failure. The real concern with most beams is with the diagonal tension stress, which results from a combination of shear stress and longitudinal flexural stress. In order to study this more extensively, it is essentially important to reinforce beams with steel bars at the tension side. The location and orientation of the cracks and diagonal cracking load can be studied as flexural failure will occur before shear failure if the member is overloaded. Diagonal cracking which forms through the beam web is due to the principal tensile stress within the shear span exceeding the tensile strength of concrete.

Empirical formulas derived from the experimental results are not an all-conclusive fundamental theory that can be applied to all cases as some variables are controlled. Arslan (2012) mentioned that with respect to the various empirical formulas, considerable differences exist as a result of the factors below:

a) the uncertainty in assessing the influence of complex parameters in a simple formula
b) the scatter of the selected test results due to inappropriate tests being considered
c) the poor representation of some parameters in tests
d) the concrete tensile strength often not being evaluated from control specimens

1.3 OBJECTIVE

The main purpose of this project is to investigate the shear failure mechanism of reinforced concrete beams without stirrups. The other objectives include:

- To predict the theoretical capacity of RC beams without stirrups using the existing empirical formula
- To investigate the modes of failure and shear behavior of RC beams without stirrups
- To compare the results of shear capacity between experimental and theoretical results
- To obtain the shear-strain distribution under the shear span studied

1.4 SCOPE OF STUDY

With limited time allocation for final year project, this project will only be focusing on aspects related to shear strength and shear span to depth ratio of RC beams. The study concentrates on analyzing the failure of reinforced beam given a span to depth ratio of a/d = 2.5, 3.0 and 4.0. It is necessary to observe that this study involves RC beams which are not reinforced with compression bars and internal stirrups. It is a general standard from past reviews conducted that the internal stirrups are not included as they provide shear reinforcement. It is also beneficial to limit the amount of aspects to be analyzed for better understanding of shear failure mechanism of RC beams. It is noted that RC beams with different size of steel reinforcement and size effect will be studied by other colleagues.

The experimental research for this project involves laboratory work and testing. A total of three(3) rectangular beams of size 100 mm (w) x 200 mm (d) x 2000 mm (l) will be casted using Grade 30 ready mixed concrete. All the beams will be reinforced with 2 T-12 bars as tensile (bottom) reinforcement. No compression (top) bars and links will be included in the RC beams.

The beam will be subjected to a 2-point loading until maximum deformation occurs. The points will be positioned at different locations for all beams to obtain the shear span ratio required. Diagonal deformation and cracking will be monitored visually.

1.5 PROJECT FEASIBILITY

The first phase of the project (FYP-1) involves the literature review on the shear strength of reinforced concrete beams without stirrups. The second phase of the project (FYP-2) involves casting of beams and also conducting experimental testing on the beams. An analytical study and interpretation of the experiment results will be done. This whole project will span over approximately 7 months.

2.0 LITERATURE REVIEW

2.1 Mechanism of Shear Failure

Authors like Nilson et al[2], stated that shear failure of reinforced concrete, or commonly called diagonal tension failure, is difficult to be predicted correctly. Beams without proper shear reinforcement are bound to fail suddenly without any warning of danger. Shear failure occurs when the shear capacity of reinforced concrete beam section is exceeded and a sliding failure develops on the beam. Hence, reinforced concrete beams are usually design to fail under flexure rather than in shear.

Another researcher, Kani[9] explained that diagonal failure occurs when the central section of a test beam under pure bending is stronger than the end sections. Due to a lack shear reinforcement, no interchange of forces occur between the steel bars and concrete except at the bar ends. The tensile force of reinforcing bars is constant throughout the whole beam. In his study, a sequence of tests had been done for which the failure was induced by cracks outside the central section of the beam. As the bending moment is largest at the centre of the beam, the cause of failure cannot be linked to the bending moment. It was concluded that the failure is caused by a constant shear force at the ends of the beams where cracks appeared.

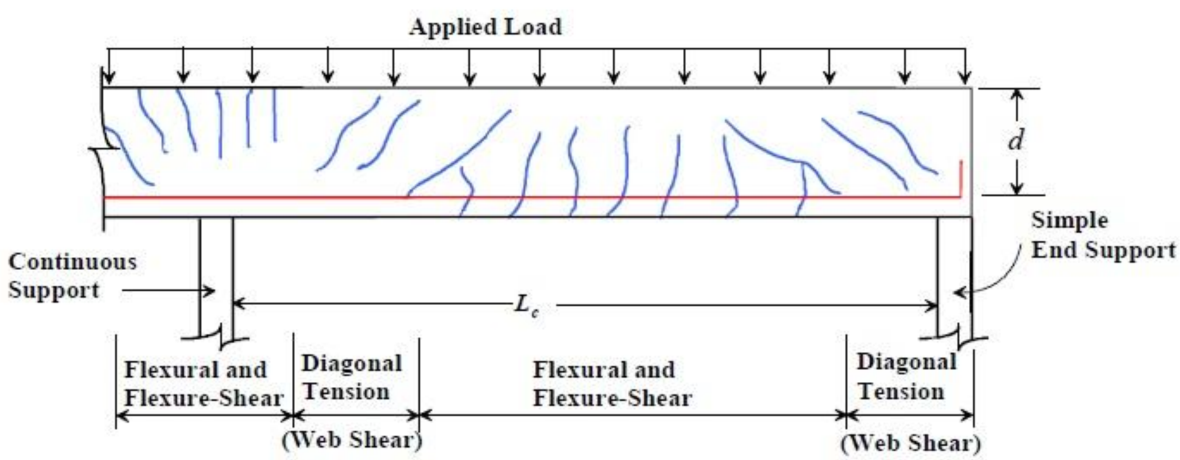


Figure 1: Types of cracks expected in a reinforced concrete beam with or without effective diagonal tension reinforcement.

Flexural cracks develop almost perpendicular to the axis of the beam in areas where the bending moments are large. Flexural shear cracks develop as an extension of the flexural crack in areas of high shear due to the diagonal tension. In the region of flexural failure, the cracks are mainly vertical in the middle third of the beam span and perpendicular to the lines of principal stresses, mainly caused by large flexural stress. Diagonal tension cracks may lead to the failure of the beam if the strength of the beam in diagonal tension is lower than its strength in flexural tension. Finally, two or three diagonal cracks expand at about 1 ½ to 2d distance from the face of the support. At this stage it is accepted that the beam has reached its shear strength. The beams categorized as intermediate beam usually fall in this type.

2.2 Shear Strength of Reinforced Concrete Beam

The shear strength of reinforced concrete beams is influenced by the shear capacity of concrete and also other parameters such as concrete compressive strength, shear span to depth ratio, tension reinforcement ratio, size effect and aggregate interlock aspects. In spite of many researches on shear in reinforced concrete beams, there is still no single all-inclusive shear failure theory.

A test experiment by Ghannoum[5] using 12 beam specimens of different sizes has been conducted. The samples were designed to fail in shear rather than bending based on the modified compression field theory. The beams were subjected to a 2-point loading arrangement with no transverse reinforcement provided and each sample having different longitudinal steel ratios. Test results showed that shear behavior of beams is influenced by size and amount of longitudinal steel.

The theoretical ultimate shear resistance of beams on a shear mode of failure consists of two factors: concrete resistance V_c and shear resistance provided by stirrups V_s. The total shear strength of the beam is as below:

$$V_a = V_c + V_s$$

In this study, $V_s = 0$ because beams are not provided with shear reinforcement.

Computation of Shear Resistance of Concrete, V_c

(i) BS 8110-1:1997

Table 3.8 — Values of v_c design concrete shear stress

$\frac{100A_s}{b_v d}$	Effective depth mm							
	125	150	175	200	225	250	300	400
	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²
≤ 0.15	0.45	0.43	0.41	0.40	0.39	0.38	0.36	0.34
0.25	0.53	0.51	0.49	0.47	0.46	0.45	0.43	0.40
0.50	0.67	0.64	0.62	0.60	0.58	0.56	0.54	0.50
0.75	0.77	0.73	0.71	0.68	0.66	0.65	0.62	0.57
1.00	0.84	0.81	0.78	0.75	0.73	0.71	0.68	0.63
1.50	0.97	0.92	0.89	0.86	0.83	0.81	0.78	0.72
2.00	1.06	1.02	0.98	0.95	0.92	0.89	0.86	0.80
≥ 3.00	1.22	1.16	1.12	1.08	1.05	1.02	0.98	0.91

NOTE 1 Allowance has been made in these figures for a γ_m of 1.25.

NOTE 2 The values in the table are derived from the expression:

$0.79\{100A_s/(b_v d)\}^{1/3}(400/d)^{1/4}/\gamma_m$

where

$\frac{100A_s}{b_v d}$ should not be taken as greater than 3;

$\left(\frac{400}{d}\right)^{\frac{1}{4}}$ should not be taken as less than 0.67 for members without shear reinforcement;

$\left(\frac{400}{d}\right)^{\frac{1}{4}}$ should not be taken as less than 1 for members with shear reinforcement providing a design shear resistance of ≥ 0.4 N/mm².

For characteristic concrete strengths greater than 25 N/mm², the values in this table may be multiplied by $(f_{cu}/25)^{1/3}$. The value of f_{cu} should not be taken as greater than 40.

Table 1: Values of V_c design concrete shear stress

(ii) Eurocode 2

$$V_{Rd,c} = C_{Rd,c} k (100 \rho_l f_{ck})^{1/3} b_w d$$

$C_{Rd,c}$	*coefficient derived from tests (recommended 0,12)*
k	*size factor = 1 + √(200/d) with d in meter*
ρ_l	*longitudinal reinforcement ratio (≤0,02)*
f_{ck}	*characteristic concrete compressive strength*
b_w	*smallest web width*
d	*effective height of cross section*

2.3 Shear Span to Depth Ratio (a/d)

A few researchers namely Kim and Park[1] mentioned that the shear failure of a reinforced concrete beam without web reinforcement is divided into 2 modes, as shown in Fig.2. The inclined cracking load exceeds shear compression load for shear span to depth ratio, a/d, greater than 2.0 – 3.0. The formation of crack, usually known as diagonal tension crack, indicates that the beam is unstable and fails. Shear compression failure on the other hand occurs when failure load exceeds the inclined cracking load, as in the case for a/d less than 2.0 – 3.0. For slender beams, shear force is carried by the shear resistance of uncracked concrete in the compression zone, the interlocking of aggregates and the dowel action of the longitudinal reinforcement. It is also stated that shear strength of reinforced concrete beams without web reinforcement is highly dependent on concrete strength, longitudinal steel ratio, shear span to depth ratio and effective depth.

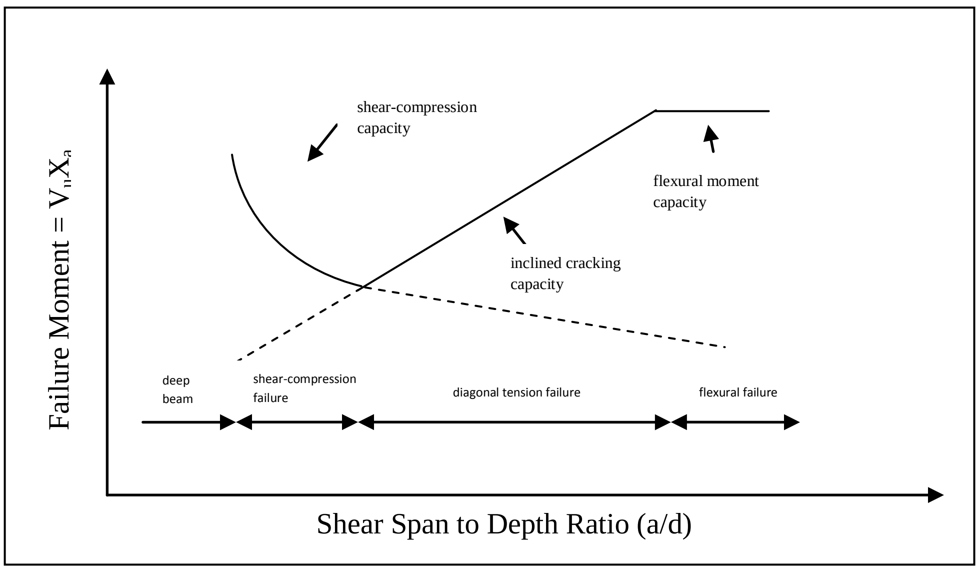


Figure 2: Shear failure mode with respect to shear span to depth ratio

Kotsovos[6] mentioned that tests on reinforced beams under a single point load indicated that diagonal failure of beams without shear reinforcement occurs closer to the support (Figure 3). It also proposed that the reasons for diagonal failure are related to the transfer of both longitudinal compressive force C, due to bending action and the shear force V to the support. Experimental results discovered that the mode of diagonal failure is affected by shear span to depth ratio, presence of shear reinforcement and amount of longitudinal reinforcement. It is also found that the compressive strength of concrete has little influence on the mode of diagonal failure.

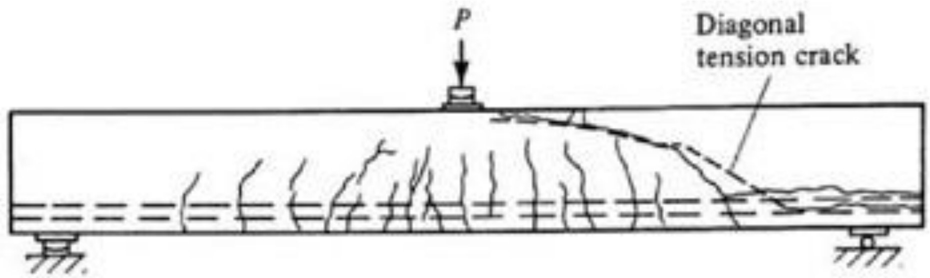


Figure 3: Longitudinally-reinforced beam without shear reinforcement

The advantage of using a two-point load testing on reinforced concrete beams is that both pure bending between the two loads and constant shear force in the end sections are combined. Based on this testing arrangement, the flexural capacity of beams and their resultant mode of failure are dependent upon the shear span to depth ratio, provided the cross-section and reinforcement are constant.

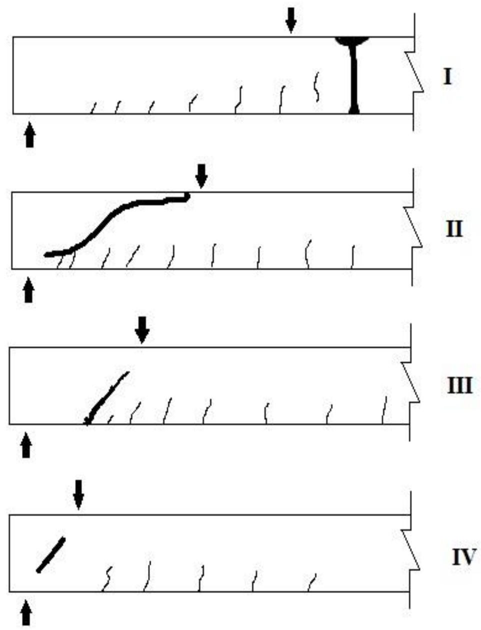


Figure 4: Types of behavior exhibited by beams under 2-point loading.

Type 1 – beam is allowed to develop full flexural capacity, flexural failure

Type 2 – flexural failure reduces with a/d, decreasing to a critical value dependent upon A_s, diagonal crack starting from tip of flexural crack closest to support to the load point.

Type 3- flexural capacity increases from the critical value in Type 2 to another value, also dependent upon A_s, at which it becomes equal to the full flexural capacity, diagonal crack forms independently of the flexural cracks

Type 4- beam is allowed to develop full flexural capacity, failure caused by diagonal crack joining the support to the load point

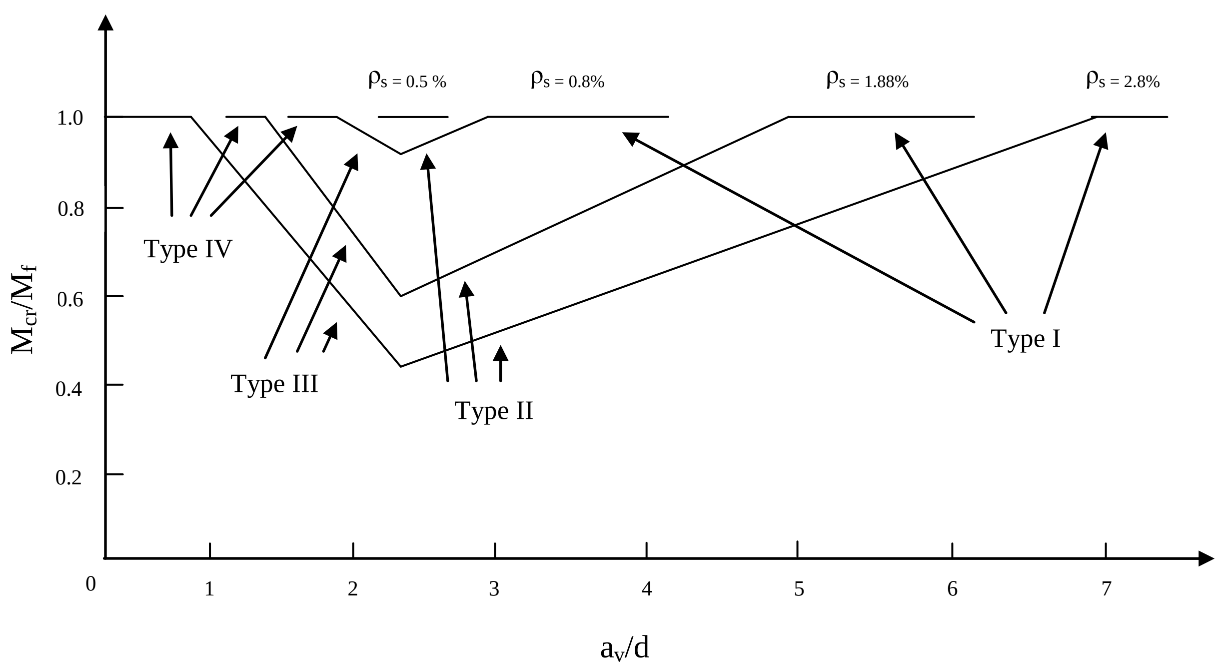
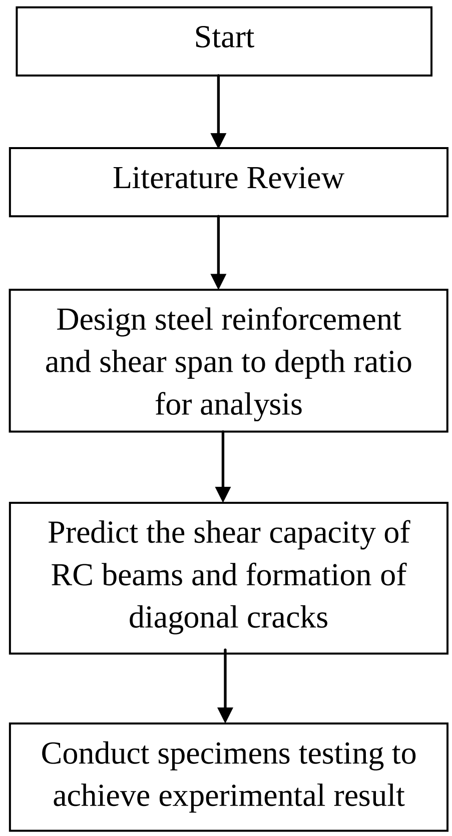


Figure 5: Graph of M_{cr}/M_f vs a_v/d

3.0 METHODOLOGY

3.1 PROJECT PROCESS FLOW



3.2 TOOLS AND EQUIPMENTS

In this project, laboratory equipments and materials are important to carry out this project work. Some of equipments and materials needed are listed as below:

- Laboratory tools and equipments
- Concrete mix of Grade 30
- Reinforcement bars (T-12)

3.3 BEAM DETAILS

A total of 3 beams of different shear span to depth ratio of 2.5, 3.0 and 4.0 will be casted. The beam size and length details are as shown in the figure below:

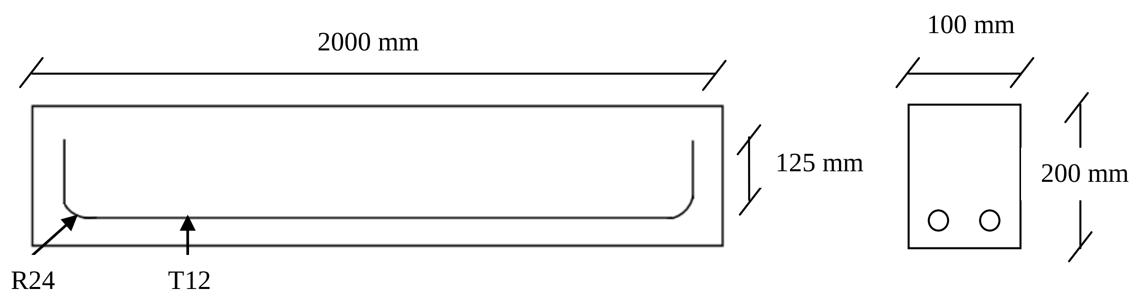


Figure 6: Beam design and beam section details

From the figure above, all beams will have a dimension of 100 mm (w) x 200 mm (d) and 2000 mm (l). All the beams will be reinforced with 2 T-12 bars as tensile (bottom) reinforcement while no compression bars or stirrups will be used.

3.4 PROJET ACTIVITY PHASES

This project will be divided into several stages of implementation to make sure every planning and procedure is followed and the project is carried out within time and reasonable to be completed.

Detailed preliminary design is being performed to make sure errors are avoided during testing phase and that the project is conducted effectively. The activity is breakdown into:

1. Preliminary design of RC beams
2. Concrete Casting
3. Analysis on steel tensile strength
4. Testing of RC beams

For the FYP 1, activity 1 will be conducted and the rest will proceed in FYP 2.

3.4.1 Preliminary design of RC beams

Beam dimension is: 100mm (w) x 200mm (d) x 2000mm (l) with a cover of 20 mm. The proposed reinforcement of 2T-12 reinforcement bars will contribute an area of 226.2 m^2 longitudinal reinforcement with an effective depth of 174mm.

Compressive force $C = 0.67 f_{cu}(0.9x)(b)$ Assume $f_{cu} = 30\ N/mm^2$

$$= 0.603 f_{cu} bx$$

$$= 0.603(30)(100)x$$

$$= 1809x$$

Tensional force $T = A_s f_y$ Assume $f_y = 460\ N/mm^2$

$$= 226.2(460)/1000$$

$$= 104\ kN$$

Compressive force = Tensional force

$$1809x = 104\ kN$$

$$x = \frac{104}{1809}$$

According to BS8110 – For over-reinforced beam x ≥ 0.5d

$x = 57 < 0.5d = 0.5(174) = 87mm$ - **Under-reinforced beam**

Moment capacity of the beam can be calculated after determining its lever arm, z.

$$Z = d - 0.5(0.9x)$$

$$= 174 - 0.5(0.9 \times 57)$$

$$= 148.35\ mm$$

Moment capacity $= TZ$

$= 104 \times (0.148)$

$= 15.43\ kN.m$

Maximum Moment Flexural Capacity $= 0.67 f_{cu}(0.9x)(b) \times Z$

$= 1809x \times Z$

$= 1809(57) \times 148.35 = 15.27\ kN.m$

BS 8110-1:1997

$$V_c = \frac{0.79}{\gamma_m}(100\frac{A_s}{bd})^{1/3}(\frac{400}{d})^{1/4}(\frac{f_{cu}}{25})^{1/3}$$

$= 0.9025\ N/mm^2$

EUROCODE 2

$$V_c = 0.12k(100\rho_1 f_{ck})^{\frac{1}{3}}$$

$= 0.12\ (1 + \sqrt[2]{\frac{200}{d}})(100\frac{A_s}{b_w d}\ f_{ck})^{\frac{1}{3}} \quad = 0.843\ N/mm^2$

3.4.2 Concrete Casting

The concrete grade used for this experiment is Grade 30. Before casting the concrete, external contractors have been hired to build the formwork for the beams. They also did the bar bending for the T12 bars.

Photo 1: Formwork

Photo 2: T12 bars

Concrete cover of 20mm thick is prepared by cutting concrete cubes of 50mm thick.

Photo 3: Labeling dimensions

Photo 4: Concrete cubes

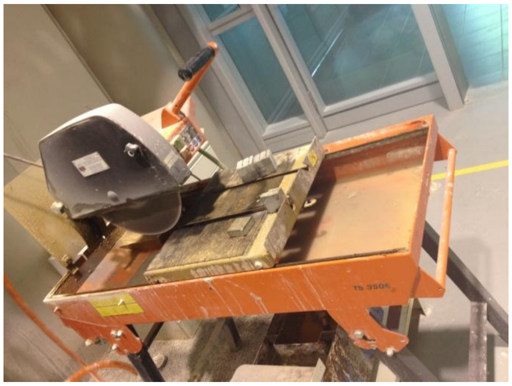


Photo 5: Concrete cubes are cut using rock cutter

Photo 6: Moulds of 100mm x 100mm greased

Photo 7: Formworks greased and steel bars are placed inside the formwork

Photo 8: Concrete covers placed below the steel bars

Photo 9: Preparing hooks

Photo 10: Concrete to be poured into the formworks

Photo 11: Concrete compacted using vibrator and leveled using screed

Photo 12: Concrete casted into 9 moulds for 28-day testing

Photo 13: Concrete curing

An external contractor, OKA ReadyMixed Concrete Sdn. Bhd. was hired to supply ready-mix concrete of Grade 30. They provided info on the slump test which is 85±25mm, Ordinary Portland Cement (OPC) and granite are used, maximum aggregate size is 20mm and the admixture used is Sika R6. Compaction of concrete is done using vibrator and this is done by me and my colleagues. Concrete curing is done by placing gunny sacks on top of the specimens and watering them every day. After 24 hours, the 9 concrete cubes are taken out from the moulds and placed inside water for 28 days for curing. Compressive strength test will be done 7 days and 28 days after curing.

3.4.3 Analysis of Steel Tensile Strength

Photo 13: Universal Testing Machine 1000 kN

Photo 14: T12 bar being clamped onto the machine

Tensile strength tests are done on 2 T12 steel bars using the 1000kN Universal Testing Machine. The steel bars are cut approximately at a length of 670 mm and the load is set at a rate of 1kN/sec.

3.5 EXPERIMENTAL SETUP

Beam : 100mm (w) x 200 mm (h) x 2000mm (l)

Figure 7: Two-point loading experimental setup

The beam will be loaded with 2-points loading until maximum deformation occurs. The points will be positioned at different locations for all beams to obtain the specified shear span to depth ratio. Diagonal deformation and cracking will be monitored visually.

3.6 GANTT CHART

FYP 2

	Action items	1	2	3	4	5	6	7	**Mid-Semester Break**	8	9	10	11	12	13	14
1	Project Work Continues															
2	Submission of Progress Report															
3	Project Work Continues															
4	Pre-EDX															
5	Submission of Draft Report															
6	Submission of Dissertation															
7	Submission of Technical Paper															
8	Oral Presentation															
9	Submission of Hard Bound Dissertation															

	Suggested Milestone
	Process

4.0 RESULTS AND DISCUSSIONS

4.1 Compressive Strength Test

Photo 15: Compressive strength test

Compressive strength test was conducted on 3 cubes which were cured for 7 days. The compressive strength is measured by breaking concrete cube specimens in a compression testing machine. The compressive strength is calculated from failure load divided by cross-sectional area resisting the load.

Failure Load (N)	Cross-sectional area (mm^2)	Compressive strength (N/mm^2)
155700	10000	15.57
176000	10000	17.60
155800	10000	15.58

Table 2: Compressive strength after 7 days

Average compressive strength = $\frac{15.57+17.60+15.58}{3} = 16.25\ N/mm^2$

The strength of concrete increases with age. Table 3 shows the strength of concrete at different ages in comparison with the strength at 28 days after casting.

Age	**Strength per cent**
1 day	16%
3 days	40%
7 days	65%
14 days	90%
28 days	99%

Table 3: Strength of concrete at different ages

By using the table as a reference, it is theoretically deduced that the compressive strength should be 65% of the concrete strength after 7 days. Hence, 0.65 x 30 = 19.5 N/mm^2. From the testing done, the average compressive strength obtained is 16.25 N/mm2. The theoretical and experimental values are not too far apart. Another testing is done on the 28th day to determine the compressive strength of the concrete.

Failure Load (N)	Cross-sectional area (mm^2)	Compressive strength (N/mm^2)
323200	10000	32.32
344300	10000	34.43
361600	10000	36.16
352700	10000	35.27
328200	10000	32.82
352300	10000	35.23

Table 4: Compressive strength after 28 days

$$\text{Average compressive strength} = \frac{32.23+34.43+36.16+35.27+32.82+35.23}{6}$$

$$= 34.37 \text{ N/mm}^2$$

From the table, the theoretical compressive strength of the concrete after 28 days should be 99% of the concrete strength. Thus, 0.99 x 30 = 29.7 N/mm^2. From the testing done, the average value is 34.37 N/mm^2. The mix design complied with the design specifications as the results showed that the concrete strength achieved is higher than required compressive strength of 30 N/mm^2.

4.2 Steel Tensile Strength Tests

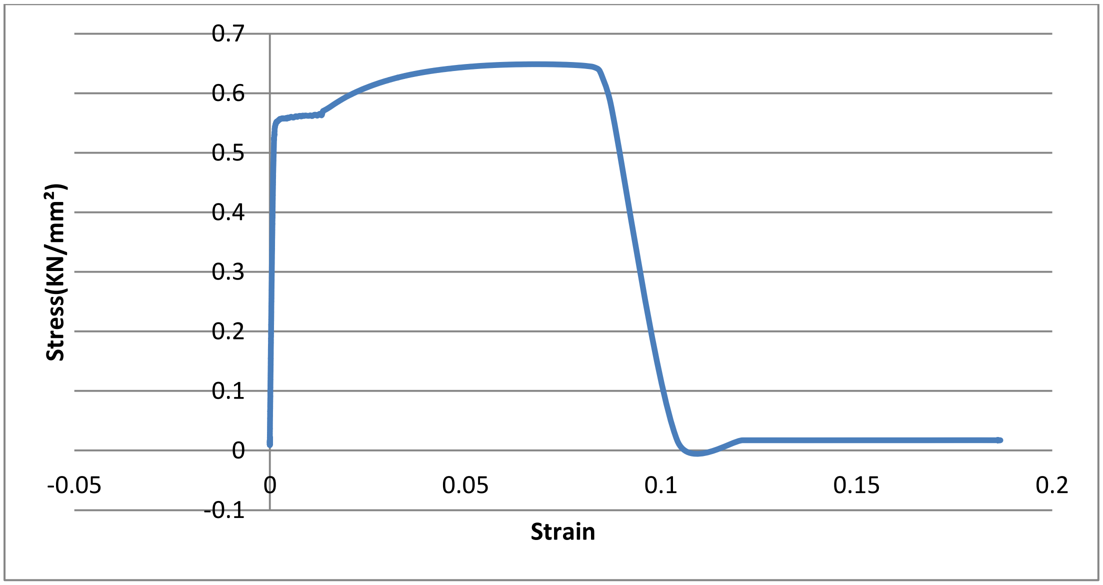


Figure 8: Stress-Strain Graph of 12mm Ybar-Sample 1

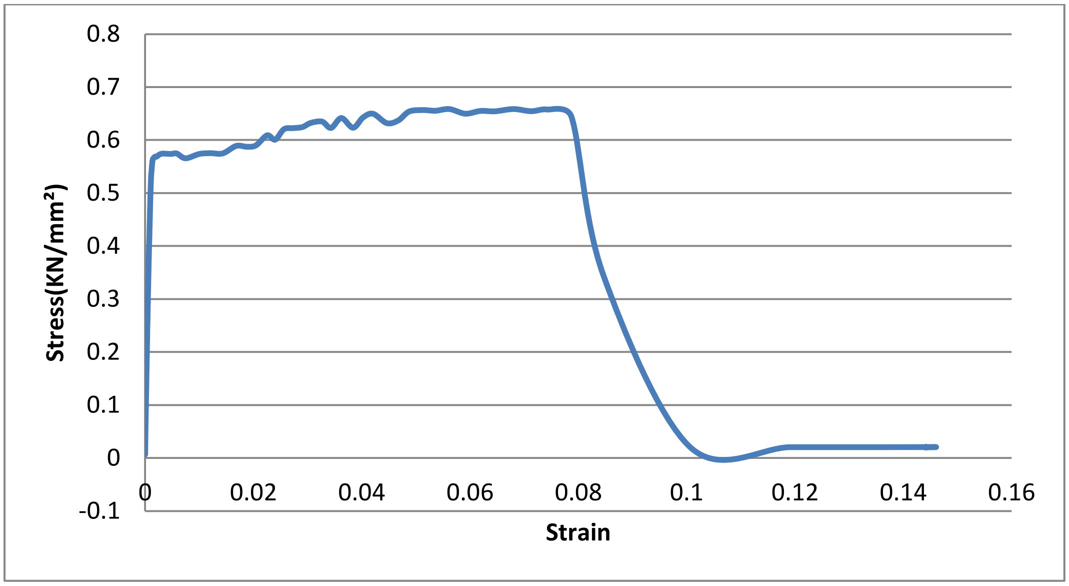


Figure 9: Stress-Strain Graph of 12mm Ybar-Sample 2

Average Load at Failure $= \frac{73.358+74.473}{2} = 73.92\ kN$

Based on the graphs, the average value of the load at failure is 73.92 kN. Ultimate tensile strength is the maximum stress that a material can withstand while being stretched or pulled before necking. The strain is obtained by dividing the deflection with the original length of the steel bar which is 670mm. As both steel bars fail at approximately the same failure load, it is safe to infer that the tensile strength of the steel bars used for this experiment is consistent. The theoretical tensile strength for a T12 bar is 636 N/mm^2. Assuming the load at failure to be 72kN, the tensile strength of the steel bars tested is 72000N/113.1mm^2 = 636.62 N/mm^2.

4.3 4-Point Load Test

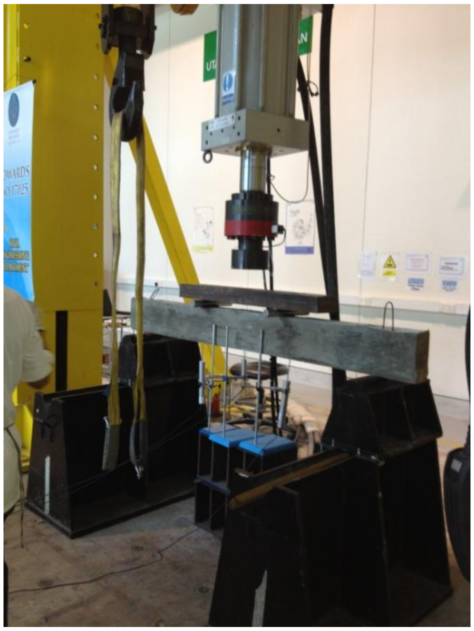


Photo 16: Preparation for 4-point load testing

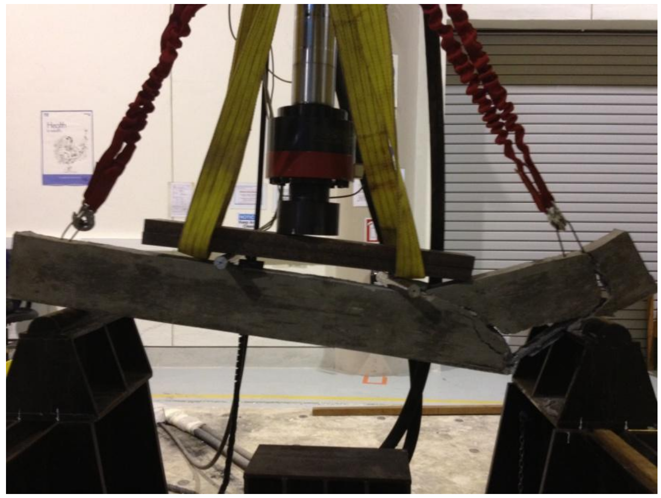


Photo 17: Beam failure under loading

Photo 18: Diagonal failure in between point of loading and support

4-point load testing is done on 3 beams of varying shear-span-to-depth (a/d) ratios. Each beam is reinforced with 2T12 bars as tensile reinforcement bars. The shear-span-to-depth ratio selected for this project is 2.5, 3.0 and 4.0. Before the beams are placed on the support, strain gauges are installed on the beam at a distance determined by the shear-span-to-depth ratio. The purpose is to measure any horizontal displacement that may occur during loading and to document the displacement against loading applied at that time of measurement. In order to measure the deflection of the beam under loading, 3 linear variable displacement transformer (LVDT) devices are placed directly under the 2 point loads and the centre of the beam. The deflections determined by the loading machine are then compared to the deflections measured by the LVDT.

Shown below are the tabulated results of the loading and deflection given by the loading machine as well as deflection recorded by the LVDT device.

Shear-span-to-depth (a/d) ratio	Failure Load (kN)	Deflection (mm)
2.5	46.88	7.524
3.0	40.53	7.067
4.0	36.29	6.824

Table 5: Failure load and deflection with respect to shear-span-to-depth (a/d) ratio

Experimental Failure Load (kN)	Theoretical Failure Load (kN)
46.88/2 = 23.44	15
40.53/2 = 20.265	15
36.29/2 = 18.145	15

Table 6: Experimental failure load (kN) and theoretical failure load (kN)

Deflection (mm)	LVDT Deflection (mm)
7.524	6.718
7.067	6.133
6.824	5.669

Table 7: Deflection recorded by loading machine and LVDT

One of the objectives of this experimental study is to obtain the shear-strain distribution under the shear span studied. Unfortunately, all the 3 beams failed to give adequate horizontal displacement as cracking occurs. The first beam with a/d ratio of 2.5 is loaded at a rate of 0.1 kN/s and failed at a load of 46.88kN without any signs of visible cracking. Thus, it is decided that the other 2 beams are to be loaded at a rate of 0.01 kN/s but the beams have also failed immediately without showing any cracking. Thus, data is unable to be collected to study the shear-strain distribution under the shear span studied.

Another objective of the project is to compare the results of shear capacity between experimental and theoretical results. From Table 6, it can be noticed that the theoretical failure load of the beam based on BS 8110-1:1997 is 15 kN while the experimental results are 23.44 kN, 20.265 kN and 18.145 kN. All 3 beams have exhibited higher ultimate shear resistance of beams as compared to the theoretical value. Percentage deviation is calculated for each value and it is determined as 36%, 26% and 17.3% respectively using the following formula;

Percentage deviation = $\frac{Experimental - Theoretical}{Experimental}\ x\ 100\%.$

The deflections recorded by both the loading machine and LVDT have shown a relatively consistent trend in which the deflection decreases as the failure load decreases. It showed that the percentage deviation is relatively small, which are 10.71%, 13.22% and 16.93% as calculated from the equation;

Percentage deviation = $\frac{Deflection(machine) - Deflection(LVDT)}{Deflection(machine)}\ x\ 100\%$

Despite the beams failing without showing any cracking, it can be clearly observed that the diagonal crack starts from tip of flexural crack closest to support to the load point. The beams exhibited a Type II behavior, as illustrated in Figure 4. Arslan[8] mentioned that past experimental results by other researchers have shown that shear failure of reinforced concrete beams without stirrups is always dominated by diagonal tension failure mode rather than compression failure mode. The diagonal cracking shear strength of RC beams is studied and analyzed to be able to determine the minimum amount of stirrups and to acquire the shear strength of RC beams with stirrups.

5.0 CONCLUSION AND RECOMMENDATIONS

As of week 12, the casting of beams, compression strength test, tensile strength test and 2-point load test have been carried out. Concrete curing is done every day to ensure that the concrete will achieve its maximum compressive strength by the end of 28 days. The average compressive strength of concrete obtained after 7 days is 16.25 N/mm^2 while the average compressive strength of concrete obtained after 28 days is 34.37 N/mm^2. The steel tensile strength tests are conducted using 2 T12 steel bars and the results showed that the ultimate tensile strength of theT12 steel bar is 636.62 N/mm^2, which is the load before necking occurs.

The 4-point load testing has been done on the 3 beams at shear span to depth ratios of 2.5, 3.0 and 4.0. The experimental results obtained are 23.44 kN, 20.265 kN and 18.145 kN. These values are compared to the theoretical value which is 15kN, calculated based on BS 8110-1:1997. All 3 beams have exhibited higher ultimate shear resistance of beams as compared to the theoretical value. Shear-strain distribution is unable to be achieved as all beams have failed before visible cracking occurs. The horizontal displacement of the strain gauges remained the same until the failure of the beams, thus no data could be collected.

The beams exhibited Type II behavior which is the diagonal crack starts from tip of flexural crack closest to support to the load point. The diagonal crack formed within the shear span studied and in between the strain gauges installed. Horizontal displacement of the strain gauges could have been obtained if cracking is allowed to occur in this project.

One recommendation for the experiment would be to ensure that the lengths of the reinforcement bars are consistent with the design prepared. This is to make certain that the beam will not fail in the way as shown in Photo 18. Besides that, it is recommended that compression bars are used for the beams so that the beams will not fail under compression. This project aims to study the diagonal tension failure of beams, thus it is highly suggested that these compression bars are used to ensure the failure mode can be studied. More specimens should be prepared to acquire a more accurate and consistent results, hence more budgets should be allowed to carry out such projects.

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